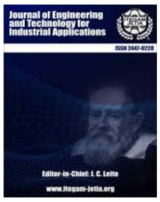
Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

Manaus, v.8 n.38, p. 37-44. Nov/Dec, 2022.
DOI: https://doi.org/10.5935/jetia.v8i38.842

ISSN ONLINE: 2447-0228



RESEARCH ARTICLE OPEN ACCESS

OFF-GRID MOBILE PHONE CHARGING SYSTEMS FOR RURAL ENERGY NEEDS

Ayodeji A. Okubanjo*[1], Alexander A. Okandeji[2] and Martins Osifeko[3]

[1] Department of Electrical and Electronics Engineering, Olabisi Onabanjo University, Nigeria.
[2] Department of Electrical and Electronics Engineering, University of Lagos, Nigeria.
[3] Department of Compute Engineering, Olabisi Onabanjo University, Nigeria.

[1] http://orcid.org/0000-0003-1908-0365, [2] http://orcid.org/0000-0002-5918-4153, [3] http://orcid.org/0000-0002-9350-6056

Email: *okubanjo.ayodeji@oouagoiwoye.edu.ng, aokandeji@unilag.edu.ng, osifeko.martins@oouagoiwoye.edu.ng

ARTICLE INFO

Article History
Received: December 22th, 2022
Accepted: December 30th, 2022
Published: December 31th, 2022

Keywords:
Off-grid,
Mobile Phone,
Charging System,
Energy Demand,
Example five.

ABSTRACT

For several decades, rural electrification has remained a formidable challenge, particularly in Nigeria. Financial constraints, difficult rural terrain, inefficient policy, and a lack of industrial community development have all contributed to the grid expansion problem in these areas. These areas are energy-deficient, and their energy demands to keep up with cutting-edge communication technology are constantly rising. As a result, rural areas are confronted with the issue of charging. Consequently, many rural residents are forced to rely on diesel/petrol generators or travel long distances and pay a premium to have their mobile phones charged. Thus, this paper proposes an off-grid solar-powered charging system as an alternative, sustainable solution to meet rural mobile phone energy demand. The methodology employed six-tier architectural features, with the economic comparison metric based on net present value and payback period. Furthermore, the proposed model's performance analysis revealed that the charging rate is dependent on the phone battery type and charger type. Furthermore, the off-grid mobile charging system has a higher net present value ($20,658US) and a shorter payback period of 2.5 years than the alternative investment of a gasolne generator.

I. INTRODUCTION

Access to energy has long been recognized as a key component in alleviating poverty, improving economic status, and promoting sustainable development [1]. Global energy demand is rapidly increasing with major growth in sub Saharan African[2]. Hence, the demand for electricity exceeded the capacity of the grid, resulting in an energy imbalance. Unfortunately, energy production in terms of generation has declined significantly over the years and most energy users rely on non-renewable energy sources such as biomass/fuelwood, natural gas, and diesel/petrol generators to meet this growing demand. For a plethora of reasons, the use of energy-efficient technology and renewable energy have recently become a focus in rural electrification projects in emerging nations seeking to meet the Sustainable Development Goals (SDGs).

African countries are endowed with a wealth of natural and renewable resources, but they lack access to electricity, clean energy, and energy security [3]. As of 2020, nearly 770 million people in Africa lack access to electricity services, accounting for 55% of the global population, with the majority of them living in rural areas [4]. Table 1 shows that Nigeria currently has limited access to electricity in comparison to other African countries. These countries have seen significant improvements as a result of increased use of renewable energy sources to alleviate rural bottlenecks and accelerate rural electrification.

Table1: Electricity Access by Country (Cameroun., Nigeria, Ghana, Tunisia, Morocco, and South Africa).

Country	Electricity Access rate in 2020	Renewable energy share target (%)
Cameroun	91%	n.a by 2030
Nigeria	75%	6% by 2030
Ghana	85%	10% by 2030
Tunisia	100%	30% by 2030
Morocco	100%	52% by 2030
South Africa	84.4%	75%% by2030

Source: Authors, (2022).

Furthermore, the proliferation of mobile phones (MPs) and recent advances in communication technology are rapidly increasing electricity demand, contributing to Nigeria's energy deficit. Nigeria currently has over 98 million mobile phone (MP) users. Unfortunately, the expansion of the MPs network without adequate growth in the grid network has denied access to electricity to over 90 million MPs. As a result, users who want to charge their MPs but do not have access to electricity face a charging problem, especially in rural areas where there is a high demand for MPs. MP users were sometimes forced to travel long distances and pay a higher cost to charge their MPs because they were not connected to the grid network. In order to meet their electricity needs, these MPs users rely primarily on the use of gasoline generators. Consequently, CO2 emissions and other high-polluting emissions have increased, contributing to environmental degradation and global warming. However, the desire for carbon reduction and stable electricity access has led to the development of solar-powered multiple cell phone charging booths.

Several studies [5]–[7] have used photovoltaic (PV) solar to charge MPs. [8], demonstrated a low-cost porotype solar-cell-powered smart phone charger. Forest et.al. [9], developed a software based platform for testing solar powered chargers. Jemal et al.[10], created a solar power pack to charge MPs. [6], used an experimental approach to investigate the power and energy consumption of MPs charging. Their findings show that the average energy use per MP charger ranges from 7Wh to 13Wh, and inverter efficiency is directly proportional to the number of MPs. Furthermore, it should be noted that single and multiple phones have nearly 50% and 85% efficiency, respectively, and that the peak power of an MP is approximately 7W. A photovoltaic (PV) system is used to recharge MPs. Schuss et al.[11], presented designed requirements for solar-powered MP chargers and suggested that conventional chargers should be modified to meet user demands. [12], proposed a solar-powered charging station for MPs. Talit [13], powers MPs with a wireless charger. His findings highlight the significance of light intensity in wireless charger charging time. Qutaiba [14], designed a solar-powered phone charging station.

The [15], investigated the factors influencing MPs in Nigeria. Their findings reveal a variety of factors that influence the use of MPs in Nigeria. Sada et al. [16], used Simulink to analyse the performance of a PV module and a thermoelectric generator for MPs charging. According to their findings, the charging voltage should not exceed 4.5 to 5V, and there is no limit on the amount of current that can be used to charge a battery, MPs, or tablets.

Solar energy harvesting is a key sustainable pathway for enhancing rural electrification projects and meeting some of Africa's SDGs, particularly in Nigeria. In fact, the use of sustainable energy has enormous energy and cost savings potential. Therefore, the objective of the present study is to develop a solar powered multiple mobile phone charger that can:

- Offset grid energy insecurity in rural areas for MPs charging applications.
- Reduce extra costs associated with MPs charging in the absence of grid connection.
- To reduce reliance on fossil-fuel-based generators and reduce CO_2 emissions.

II. MATERIALS AND METHODS

II.1 PHOTOVOLTAIC CELL (PV)

A photovoltaic (PV) cell, also known as a solar cell, directly converts solar energy into electrical energy. PV cells are connected in a series configuration to form module. The PV module is simplified by using a single diode mathematical model. Each N_P solar cell in solar panel is affected model by current, voltage, temperature and solar irradiation. Hence, the total electric power generated by the PV cells is given in Eq.1.

$$P_{pv} = f\left(A_{PV,} I_{PV,} T_{PV,} V_{OC,} \alpha_{PV,} I_o, H_{PV,} m_{PV}\right) \quad (1)$$

Where, $A_{pv,}$ is the panel surface area $\left[m^2\right]$, I_{SC} is the open circuit current $[A]$, (T_{PV}) denotes solar cell temperature $[K]$, V_{OC} open circuit voltage $[V]$, α_{pv} is the tilt angle of PV module towards light source $\left[^o\right]$, I_O is the specific cell current $[A]$, H_{pv} denotes the solar irradiation $\left[w/m^2\right]$, and m_{SC} is the material of the PV module.

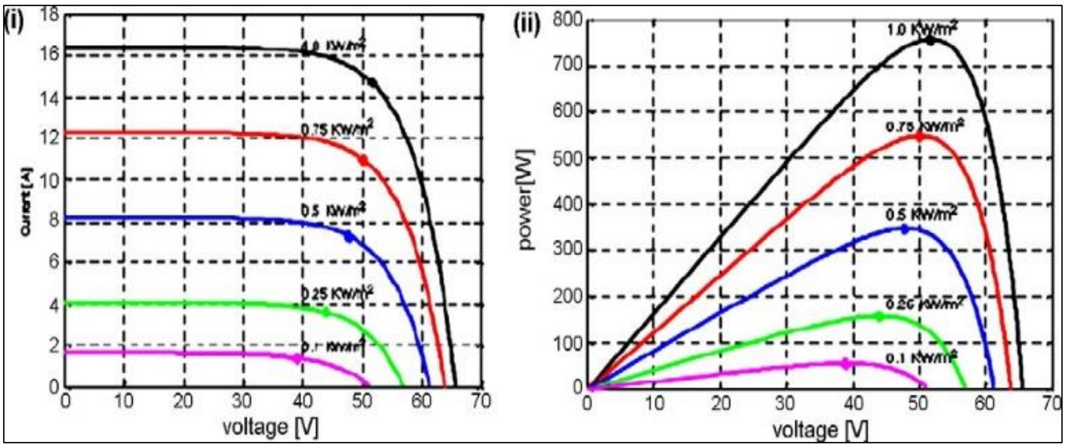


Figure 2: (i) Photovoltaic cells I-V curve and (ii) Photovoltaic cells P–V curve.
Source: [17].

The power-voltage curve characteristic for a photovoltaic array operating at a typical irradiance and temperature of 1000 w/m^2 and $25^o C$ respectively is shown in Fig. 2. The solar irradiation H_{PV} varies with time. Hence, the PV output is dependent on the variation in solar irradiation such that H_{PV} are evaluated as proposed by [18] as:

$$H_{pv} = R_b \left[H_b + H_d \left(1 + \frac{1}{R_a} \right) \right] \quad (2)$$

Where R_a is the tilt factor for the beam, H_b and H_d are the global and diffuse irradiation $\left[Kwh/m^2 \right]$. The theoretical relationship between the solar panel efficiency and the solar cells temperature is given by [19] as:

$$\eta_{pv} = \eta_o \left[1 - \gamma_o \left(T_{pv} - T_{air} \right) \right] \quad (3)$$

Where,

$$\eta_o = \eta_m \eta_{pc} \quad (4)$$

Here, η_m is the solar module efficiency, η_{pc} is the power conditioning efficiency, T_c solar cell temperature, T_a ambient temperature, and γ_o is the array efficiency temperature coefficient.

II.2 BUCK CONVERTER (BC)

A buck converter serves as a dc-dc converter for the charge controller. Its purpose is to maximize power output by balancing the impedance of the solar panel and the battery. In this study, the DC converter uses tracking algorithms to track the voltage and current from the solar panels and adjusts the duty cycle of the filtering signal accordingly to achieve maximum power transfer.

II.3 SOLAR CHARGE CONTROLLER (SCC)

A solar charge controller (SCC) is a power regulator that uses maximum power point tracking (MPPT) algorithm to maximize the amount of power going into battery from PV module to prevent overcharging. It is only necessary for battery-powered systems. SCC's primary function is to monitor battery charging and discharging. The SCC extract the maximum available power from the PV module at an operating voltage $\left(V_{op} \right)$. The MPP of SCC varies with changes in temperature, solar variation H_{pv}, and ambient conditions.

For maximum power transfer the operation voltage must be equal to the voltage V^{mpp} otherwise, the obtained output power from the PV array/module $\left[P_{pv}(w) \right]$ will be less than the power that can be gained in the MPP as expressed as:

$$P_{pv} = \begin{cases} P_{pv} = P^{mpp}, V_{op} = V^{mpp} \\ P_{pv} \prec P^{mpp}, V_{op} \succ V^{mpp} \end{cases} \quad (5)$$

Due to abrupt changes in ambient temperature, V_{op} modification is sometimes required. A microcontroller unit, various sensors, and a DC-DC or buck converter are typical components of a solar PV energy harvester.

II.4 BATTERY SYSTEM (BS)

A battery is a backup energy storage device that converts chemical energy to electrical energy. The battery voltage cell in lithium-ion (Li-ion) batteries is a function of the cell's chemical energy reaction. The cathode, anode, and separator are the three main components of a Li-ion battery, as shown in Fig.3. Copper and aluminum collectors are used as anode and cathode in typical Li-ion cells, respectively. [20].

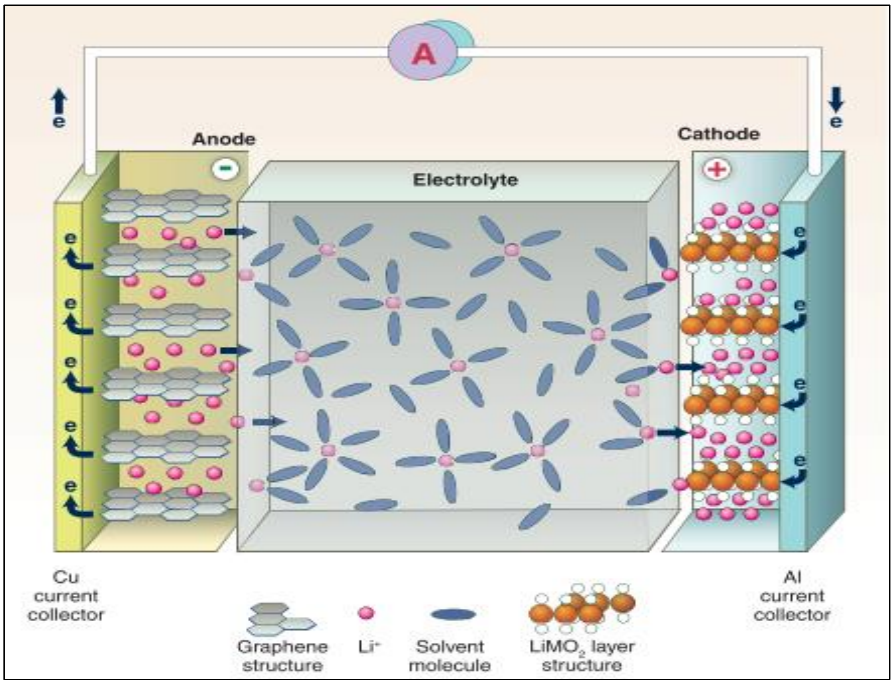


Figure 3: Schematic of Li-ion battery during discharging.
Source: [21].

Due to their longer lifespan, higher power density, and durability, lithium-ion batteries are used in a variety of applications, including electric and hybrid vehicles, smartphones, tablets, computers, wearable technology, and smart and high-tech devices. In this study, two 18650 LiPo batteries with a capacity of 26000mAh and a voltage level of 3,7V are used due to their durability, compactness, low cost, and storage capacity. The charging current I_q varies and depends on the state of charge of a mobile battery (SOC). The charging current is given by [22] as:

$$I_{qc} = \begin{cases} I_{\max}, I_{qc} \leq 80\% SOC \\ I_{\min}, I_{qc} \geq 80\% SOC \end{cases} \quad (6)$$

Hence, the state of charge (SOC) can be expressed as a function of system efficiency, solar module area and solar irradiation as:

$$SOC[\%] = \frac{P_{pv} \times \eta_{se} \times t_{mpc}}{E_{\text{bat}}} \quad (7)$$

Where,

$$\eta_{se} = \eta_{pv} \times \eta_{mpp} \times \eta_{\text{bat}} \quad (8)$$

E_{bat} denotes the charging energy of the battery $[W]$, t_{mpc} is the amount of time mobile phones are charged $[h]$. Case 1 illustrates the efficiency and time required for a mobile phone with given specifications.

Case 1:

E_{bat} =8.5W, P_{pv} =0.3W, t_{mpc} =4h, η_{se} =80%

$$SOC = P_{pv} \times \eta_{se} \times t_{mpc} / E_{\text{bat}} \approx 11\%$$
$$t_{mpc} = P_{pv} \times \eta_{se} / E_{\text{bat}} \approx 3\%/h$$

II.5 USB CONNECTOR (USB)

USB, or universal serial bus, is a notable standard interface for connecting a variety of devices to SOC, including mobile phones. Type A and Type B are the most commonly used with phones from the second and third generations. However, the proliferation of smartphones and the need for smart charging has resulted in the invention of mini-USB, micro-USB, and Type C as smart replacements for traditional USB types. USB, or universal serial bus, is a notable standard interface for connecting a variety of devices to SOC, including mobile phones.

Type A, B are the most commonly used with phones from the second and third generations. However, the proliferation of smartphones and the need for smart charging has resulted in the invention of mini-USB, micro-USB, and Type C as smart replacements for traditional USB types. USB, or universal serial bus, is a notable standard interface for connecting a variety of devices to SOC, including mobile phones. Type A and Type B are the most commonly used with phones from the second and third generations. However, the proliferation of smartphones and the need for smart charging has resulted in the invention of mini-USB, micro-USB, and Type C as smart replacements for traditional USB types.

USB 2.0 supports a charging downstream port with a voltage level ranging from 4.5V to 5.5 V with a tolerance of ±5% and a current level up to 1500mA. Figure 4 shows the user specification for USB types in terms of maximum current, power, and voltage. The smartphones use the configurations of data wires D^+ and D^- identify the current chargers.

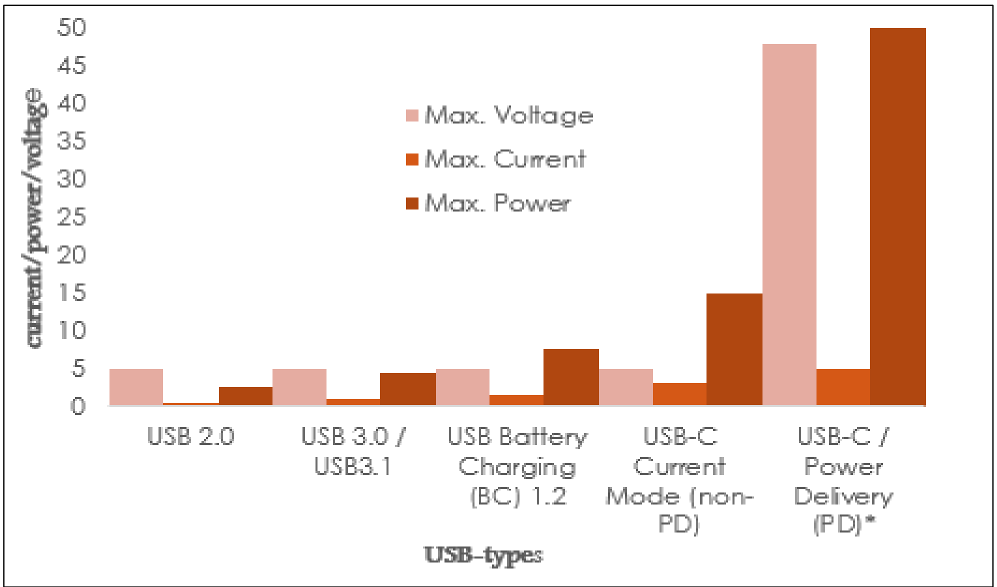


Figure 4: USB Characteristics.
Source: Authors, (2022).

II.6 SYSTEM ARCHITECTURE

Figure.5 is the conceptual framework of the proposed off-grid charging systems. The systems feature six-tiers. Tier-1 consists of a solar PV system, which is an energy harvester that converts solar energy to electricity. The study uses a 50W, 17.5V monocrystalline solar panels.. Tier-2 is in charge of power conversion and ensuring maximum power output. The charge controller unit is in Tier 3. This is a power regulator that optimizes the amount of power that the PV module sends to the battery in order to avoid overcharging. Tier-4 is the backup energy storage device. It is powered by a LiPo battery with a capacity of 2600mA and a voltage of 3.7V Tier-5 is the universal serial bus that is used to charge MPs to the SOC. Tier-6 is connected to the MPs devices via a USB cable to improve their charging status.

III. RESULTS AND DISCUSSIONS

III.1 ECONOMIC ANALYSIS

The case study is based on a college of Engineering located in rural area of Ifo local government, ogun state Nigeria. The installed capacity is 50W, which is further extended to 650W to accomodate future energy needs of the University residents. The system specification is shown in Table 2. The system life span of the gasoline generator and off-grid solar charging systems as well as operating hours is evaluated over 25 years. The investment cost of PV mobile charging systems in Nigeria is about \$1332US/W_p, operating for 6hrs/day or 308days/per year with maiintenance cost of 0.05% per year of investment cost span over lifteime of 25 years. The investment cost of 650W gasoline generator is \$200US/W, operating and maintenance cost is 1% per year of investment cost, operating for 25 years lifespan. The gasoline generator runs for 5hrs per day for duration of 322days/years.

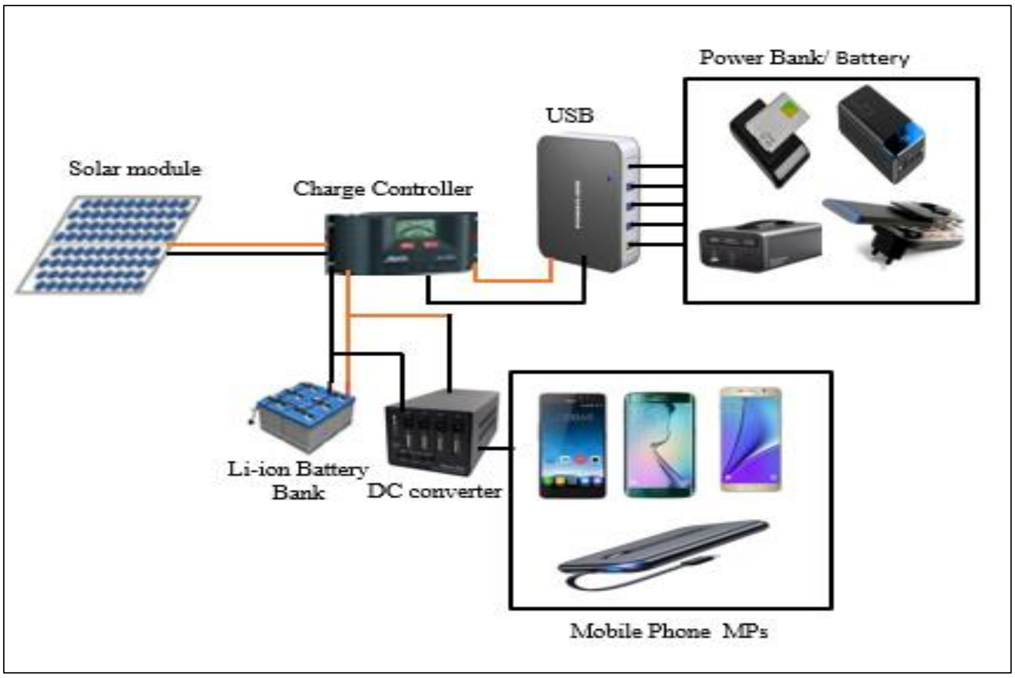


Figure 5: schematic of off-grid solar based charging systems.
Source: Authors, (2022).

Table 2: System specification of 650W PV charging systems and Gasoline based generator.

System Discription	System Specification	
Module name	c-Si modules	Gasoline engine (α -generator)
Module size/engine capacity	13(50W/module)	1 unit
Operating hour/days per years	6hrs/days 308days per year	5hrs/day 322days per year
System capacity	650W	650W
Investment cost(IC)	\$1332US	\$200US
O&M cost	0.05%/year of IC	1%/year of IC
Cost of solar/fuel per kWh	0.002kWh	0.24kWh

Source: Authors, (2022).

The cost-benefit comparison analysis of the proposed solar(PV) charging systems and gasoline generator is presented in Table 3.

Table 3: Cost-benefit Assessment for 25 years of 650W PV Charging Systems using c-Si PV modules at electricity cost of 0.12kWh.

Cost-benefit Assessment	c-Si module	α -generato
Annual benefit: Elecrticity save	\$55,440US	\$12,075US
Cummulative benefit	**\$55,440US**	**\$12,075US**
Costs:		
Investment cost	\$1332US	\$200US
O&M cost	\$16.65US	\$50US
Fuel cost	[-]	\$384.0US
Cummulative costs	**\$1348.65US**	**\$634US**

Source: Authors, (2022).

In economic assessment, there are several economic metrics adopted to ascertain economic viability of any project such metrics includes net present value (NPV), life cycle cost (LCC), benefit-cost ratio (BCR), payack period (PBP) among others. However, the NPV and PBP are important economic metrics used by investor or decision maker in ranking profitable investment projects. Such that the NPV is computed as given by [23] as:

$$\sum_{n=1}^{M} \beta_n (1+r)^{-j} - \sum_{n=1}^{M} \gamma_n (1+r)^{-j} \quad (9)$$

Where, β_n is the cummulative benefit at the end of n-years, γ_n denotes the comined cost at the end of n-years, r refers to discount rate, M refers to the number of years in project's lifetime and j denotes each year of the project's lifespan.

Similarly, for most energy-efficiency project, the PBP is the time taken by the new project to recover its cost. Hence, the PBP is given as:

$$\mathrm{PBP} = \frac{C_\delta}{S_\delta} \tag{10}$$

Where, C_δ is the cost of efficient system (c-Si PV module) and S_δ denotes the cost of annual energy saving by the efficient system.

These economic metrics is evaluated for the PV moile charging systems and a gasolin generating system and presented in Table 4

Table 4: Economic Assessment comparison between c-Si module and α -generator of 650W capacity systems.

Economic metrics $US	**c-Si modules**	**α -generator**
NPV	20,658	8,570
PBP	2.5	8.75

Source: Authors, (2022).

The economic analysis shown in Table 4 shows that the off-grid PV mobile charging system is a profitable investment with shorten payback period of 2.5 years than the alternative investment of gasoline generator. This implies that the investment cost of c-Si PV mobile phone charging system would be recovered within the 2.5 years and the investor would beining to enjoy the energy cost benefit of the system. In terms of Co2 emmission mitigation, the c-Si PV mobile phone charging system can be an added feature enefit in environmental factors and in the long-term the energy cost saving potential of the c Si Pv charging system outweight the fuel cost associated with gasoline (α **)** generator.

III.2 PERFORMANCE ANALYSIS

The proposed system was tested experimentally with various MPs. According to an online survey of students, the three most preferred MPs are the VivoY2, Redmi8, and Samsumg Galaxy Note8. Furthermore, the performance index was based on the charging time and power consumption of MPs, as shown in Figures 6-7.

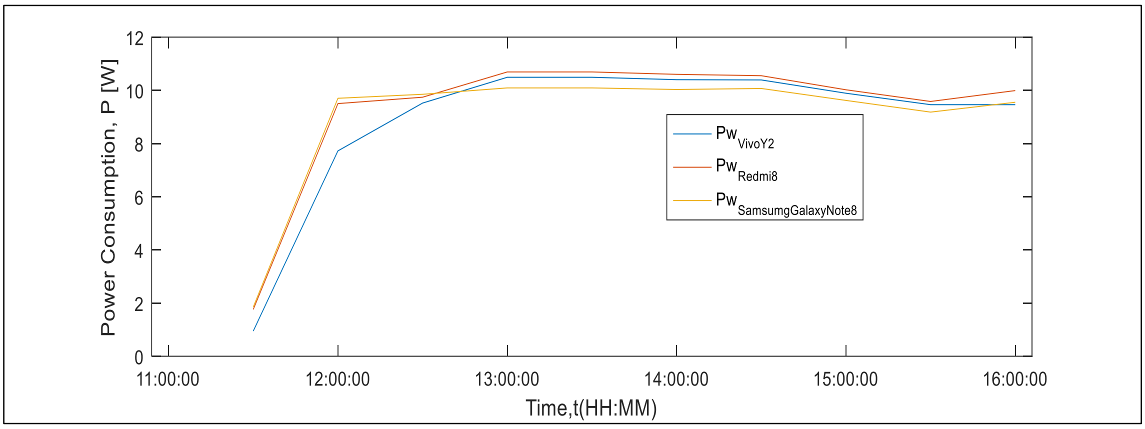


Figure 6: MPs Power Consumption.
Source: Authors, (2022).

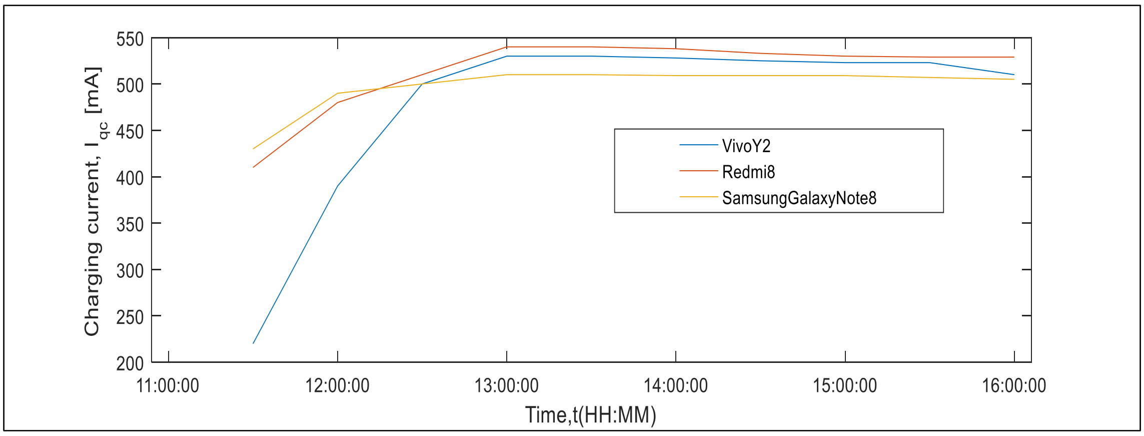


Figure 7: MPs Charging Current.
Source: Authors, (2022).

At maximum efficiency, it takes about 60 minutes to fully charge a Samsung Galaxy Note8 with a battery capacity of 3000mAH from 0% using a charger with a 2 A rating, while a Vivo-Y2 with a battery capacity of 4030mAh takes about 90 minutes to fully charge using a type C charger. Similarly, a redmi8 with a 5000mAH battery capacity takes about 120 minutes to reach full capacity. In terms of performance index, the Samsung Galaxy Note 8 outperforms in terms of charging rate and power consumption. However, their performance is dependent on the type and capacity of the MPs battery, as well as the type of charger used.

IV. CONCLUSIONS

This paper presents an off-grid solar powered charging system as a sustainable solution to rural energy demamd needs. The rising energy demand for MPs applications and other lighting devices necessitates a rapid transition to renewable energy and economical, efficient, and co-friendly off-grid energy system. Furthermore, solar energy harvesting is a key sustainable pathway for enhancing rural energy access and mitigate the bottlenecks associated with the expansion of grid network in developing countries especially, in rural terrains. In an attempt to promote clean energy, future adoption of off-grid systems in Nigeria should be viewed as a positive step toward a sustainable path to zero carbon by 2050. The use of off-grid systems is energy-saving strategy for improving energy access and offset grid energy insecurity. Prioritizing government support for off-grid systems will benefit the country's energy supply.

V. AUTHOR’S CONTRIBUTION

Conceptualization: Ayodeji A. Okubanjo.
Methodology: Ayodeji A. Okubanjo. Alexander A. Okandeji, Martins Osifeko.
Investigation: Alexander A. Okandeji, Martins Osifeko.
Discussion of results: Ayodeji A. Okubanjo.
Writing – Original Draft: Ayodeji A. Okubanjo, Alexander A. Okandeji, Martins Osifeko.
Writing – Review and Editing: Ayodeji A. Okubanjo,
Resources: Ayodeji A. Okubanjo.
Supervision: Ayodeji A. Okubanjo, Alexander A. Okandeji, Martins Osifeko.
Approval of the final text: Ayodeji A. Okubanjo. Alexander A. Okandeji, Martins Osifeko.

VI. ACKNOWLEDGMENTS

The authors would like to thank the authors whose works provided detailed information that was useful in the preparation of this manuscript. Various comments and suggestions from co-researchers were also appreciated for adding value to this work.

VII. REFERENCES

[1] S. Hirmer and P. Guthrie, “The benefits of energy appliances in the off-grid energy sector based on seven off-grid initiatives in rural Uganda,” Renew. Sustain. Energy Rev., vol. 79, no. July 2016, pp. 924–934, Nov. 2017,:http://dio.org/10.1016/j.rser.2017.05.152

[2] A. Okubanjo et al., “A Comprehensive Review of Energy Crisis in Nigeria and the contributing Role of Renewable Energy,” Sci. Forum (Journal Pure Appl. Sci., vol. 20, no. 3, p. 284, 2020, http://dio.org/10.5455/sf.89651

[3] A. Okubanjo, O. Godswill, and O. Patrick, “Cost Optimization of Hybrid Solar/ Heat Pump Water Heating System : Model Formulation,” in 2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), 2022, pp. 1–5, mailto:http://dio.org/10.1109/NIGERCON54645.2022.9803094.

[4] F. Birol, “Energy Policies Beyound IEA Countries,” Int. Energy Agency, p. 221, 2019.

[5] M. Madziga, A. Rahil, and R. Mansoor, “Comparison between Three Off-Grid Hybrid Systems (Solar Photovoltaic, Diesel Generator and Battery Storage System) for Electrification for Gwakwani Village, South Africa,” Environments, vol. 5, no. 5, p. 57, May 2018, http://dio.org/10.3390/environments5050057

[6] S. C. Manchester and L. G. Swan, “Off-grid mobile phone charging: An experimental study,” Energy Sustain. Dev., vol. 17, no. 6, pp. 564–571, 2013, :http://dio.org/110.1016/j.esd.2013.10.003

[7] C. Sanitha Michail, “An Innovative Way Of Implementing Efficient Mobile Charger Powered By Solar Energy,” IOP Conf. Ser. Mater. Sci. Eng., vol. 1070, no. 1, p. 012091, Feb. 2021, http://dio.org/10.1088/1757-899X/1070/1/012091

[8] J. A. Brito-Rojas, J. A. Aguilar-Calderon, O. Garcia-Sanchez, C. Tripp-Barba, A. Zaldivar-Colado, and S. Misra, “A low-cost solar cell charger prototype for smartphone’s battery charging,” in 2014 IEEE 6th International Conference on Adaptive Science & Technology (ICAST), 2014, vol. 2015-Janua, pp. 1–5, http://dio.org/10.1109/ICASTECH.2014.7068137

[9] A. Forest, M. Dallard, and A. Shabani, “An optimized platform for performance evaluation of solar battery chargers,” in 2017 IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE), 2017, pp. 1–4, http://dio.org/10.1109/CCECE.2017.7946832

[10] J. Assres, G. Asfaha, and S. Melaku, “Design and Development of Solar Power Generating Apparels,” J. Text. Eng. Fash. Technol., vol. 1, no. 4, pp. 121–124, 2017, http://dio.org/10.15406/jteft.2017.01.

[11] C. Schuss, B. Eichberger, and T. Rahkonen, “Design specifications and guidelines for efficient solar chargers of mobile phones,” in 2014 IEEE 11th International Multi-Conference on Systems, Signals & Devices (SSD14), 2014, pp. 1–5, http://dio.org/0.15406/jteft.2017.01.00022

[12] L. E. Erickson, J. Cutsor, and J. Robinson, “Solar Powered Charging Stations,” in Solar Powered Charging Infrastructure for Electric Vehicles, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742: CRC Press, 2016, pp. 23–33, :http://dio.org/110.1201/9781315370002-4

[13] T. Jumphoo, P. Uthansakul, and H.-S. Lui, “Implementation of Wireless Charger for Mobile Phone Based on Solar Energy.,” Suranaree J. Sci. Technol., vol. 21, no. 4, pp. 283–291, 2014.

[14] Q. I. Ali, “System Based on Solar Energy Harvesting,” Iraq J. Electr. Electron. Eng., vol. 7, no. 1, pp. 69–72, 2011.

[15] I. Forenbacher, S. Husnjak, I. Cvitić, and I. Jovović, “Determinants of mobile phone ownership in Nigeria,” Telecomm. Policy, vol. 43, no. 7, p. 101812, Aug. 2019, http://dio.org/10.1016/j.telpol.2019.03.001

[16] C. R. Saha, M. N. Huda, A. Mumtaz, A. Debnath, S. Thomas, and R. Jinks, “Photovoltaic (PV) and thermo-electric energy harvesters for charging applications,” Microelectronics J., vol. 96, no. July 2019, p. 104685, Feb. 2020, http://dio.org/10.1016/j.mejo.2019.104685

[17] P. Nema, R. K. Nema, and S. Rangnekar, “A current and future state of art development of hybrid energy system using wind and PV-solar: A review,” Renew. Sustain. Energy Rev., vol. 13, no. 8, pp. 2096–2103, Oct. 2009,http://dio.org/10.1016/j.rser.2008.10.006

[18] E. M. Wanjiru, S. M. Sichilalu, and X. Xia, “Optimal Operation of Integrated Heat Pump-instant Water Heaters with Renewable Energy,” Energy Procedia, vol. 105, pp. 2151–2156, May 2017,http://dio.org/110.1016/j.egypro.2017.03.607

[19] E. Skoplaki and J. A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations,” Sol. Energy, vol. 83, no. 5, pp. 614–624, 2009, http://dio.org/10.1016/j.solener.2008.10.008

[20] A. Porras-Hermoso, S. Pindado, and J. Cubas, “Lithium-ion battery performance modeling based on the energy discharge level,” Meas. Sci. Technol., vol. 29, no. 11, 2018,http://dio.org/10.1088/1361-6501/aae231

[21] B. Dunn, H. Kamath, and J. M. Tarascon, “Electrical energy storage for the grid: A battery of choices,” Science (80-.)., vol. 334, no. 6058, pp. 928–935,

2011,http://dio.org/10.1126/science.1212741

[22] C. Schuss, T. Leikanger, B. Eichberger, and T. Rahkonen, "Efficient use of solar chargers with the help of ambient light sensors on smartphones," Conf. Open Innov. Assoc. Fruct, vol. 2014-December, pp. 79–85, 2014,http://dio.org/10.1109/FRUCT.2014.7000924

[23] A. Okubanjo, A. Okandeji, and P. Oshevire, "Hybrid Solar / Heat Pump System for Water Heating in Nigeria : Techno-economic assessment," in 2022 IEEE Nigeria 5th Information Technology for Education and Development (ITED), 2022, pp. 1–6.